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SURVEY OF CLUSTERING ALGORITHMS AND MULTIPATH ROUTING PROTOCOLS IN MOBILE AD HOC NETWORKS

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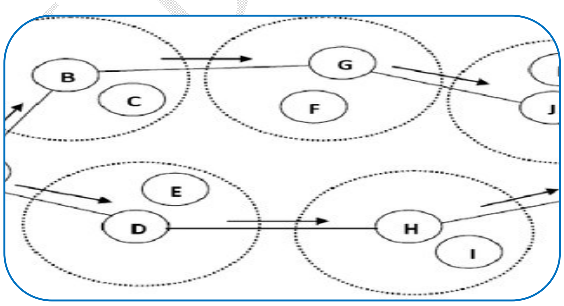
ABSTRACT :
With the advance of wireless communication technologies, small-size and high-performance computing and communication devices are increasingly used in daily life. After the success of second generation mobile system, more interest was started in wireless communications. A Mobile Ad hoc Network (MANET) is a wireless network without any fixed infrastructure or centralized control; it contains mobile nodes that are connected dynamically in an arbitrary manner. The Mobile Ad hoc Networks are essentially suitable when infrastructure is not present or difficult or costly to setup or when network setup is to be done quickly within a short period, they are very attractive for tactical communication in the military and rescue missions. The clustering is an important research area in mobile ad hoc networks because it improves the performance of flexibility and scalability when network size is huge with high mobility. Ad hoc routing faces many unique problems not present in wired networks. Particularly in MANETs where routes become obsolete frequently because of mobility and poor wireless link quality. The Multipath routing addresses these problems by providing more than one route to a destination node. Multipath routing appears to be a promising technique for ad hoc routing protocols; the multiple paths can be useful in improving the effective bandwidth of communication, responding to congestion and heavy traffic, increasing delivery reliability and security. The traffic can be distributed among multiple routes to enhance transmission reliability, provide load balancing, and secure data transmission and energy optimization. Hence in these paper surveys the different clustering algorisms and different multipath routing protocols. The combination of cluster based multipath routing is a most efficient technique in MANETs.

KEYWORDS : *MANET, Clustering, Multipath Routing,*

1. INTRODUCTION TO CLUSTERING

Clustering is an important research topic for mobile ad hoc networks (MANETs) because clustering makes it possible to guarantee basic levels of system performance, such as throughput and delay, in the presence of both mobility and a large number of mobile terminals. A large variety of approaches for ad hoc clustering have been presented, whereby different approaches typically focus on different performance metrics. This survey provides descriptions of the mechanisms, evaluations of their performance and cost, and discussions of advantages and disadvantages of each clustering scheme [1]. With this article, readers can have a more thorough and delicate understanding of ad hoc clustering and the research trends in this area.In a clustering scheme the mobile nodes in a



MANET are divided into different virtual groups, and they are allocated geographically adjacent into the same cluster according to some rules with different behaviors for nodes included in a cluster from those excluded from the cluster. A typical cluster structure is shown in Fig. 1. It can be seen that the nodes are divided into a number of virtual groups (with the dotted lines) based on certain rules. Under a cluster structure, mobile nodes may be assigned a different status or function, such as clusterhead, clustergateway, or clustermember. A clusterhead normally serves as a local coordinator for its cluster, performing intra-cluster transmission arrangement, data forwarding, and so on. A clustergateway is a non-clusterhead node with inter-cluster links, so it can access neighboring clusters and forward information between clusters. A clustermember is usually called an ordinary node, which is a non-clusterhead node without any inter-cluster-links [1].

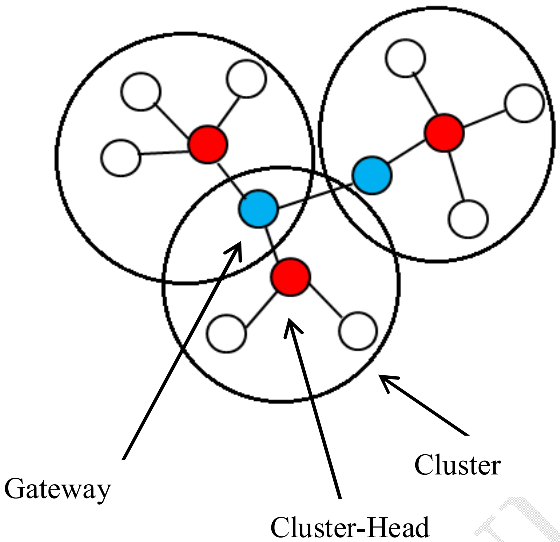


Fig. 1. Cluster structure illustration.

1.1Advantages of Clustering

Clustering in Ad Hoc networks has many advantagescompared to the traditional networks. They are as follows [2]

1) It allows the better performance of the protocol for theMedium Access Control (MAC) layer by improving thespatial reuse, throughput, scalability and powerconsumption.
2) It helps to improve routing at the network layer byreducing the size of the routing tables.
3) It decreases transmission overhead by updating therouting tables after topological changes occur.
4) It helps to aggregate topology information as the nodesof a cluster are smaller when compared to the nodes ofentire network. Here each node stores only a fraction ofthe total network routing information.
5) It saves energy and communication bandwidth in ad-hocnetworks

1.2 Issues of Clustering

The highly dynamic and unstable nature of MANET'smakes it difficult for the Cluster based routing protocol todivide a mobile network into clusters and determination ofcluster heads for each cluster. Clustering reduces communication and control overheads due to pre-determined paths of communication through cluster heads. It is vital for scalability of media access protocols, routing protocols andthe security infrastructure [1] [3].

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Routing protocols whichconsiders only bidirectional links may have link asymmetrydue inefficient or abnormal routing. Untapped networkcapacity is represented by the undiscovered unidirectionallinks, which reduces the network connectivity [1] [4].A large numbers of mobile terminals aremanaged by aMANET using a cluster topology. The construction andmaintenance of a cluster

Structure requires additional costcompared with a topology control without cluster.
Clustering has some side effects and drawbacks.
1) The maintenance cost for a large and dynamic mobilenetwork requires explicit message exchange betweenmobile node pairs. As the network topology changesquickly and concerns many mobile nodes, the number ofinformation message exchange grows to reach a criticalpoint. This information exchange consumes a lot ofnetwork bandwidth and energy in mobile nodes.
2) A ripple effect of re-clustering occurs if any local eventstake place like the movement or the death of a mobilenode, as a result it may lead to the re-election of a newcluster-head. When a new cluster-head is re-elected itmay cause re-elections in the whole of the clusterstructure. Thus, the performance of upper-layerprotocols is affected by the ripple effect of re-clustering.
3) One of the major drawbacks of clustering in MANETs isthat some nodes consume more power when compared toothers nodes of the same cluster.
As special node like acluster-head or a cluster-gateway manage and forwardall messages of the localcluster theirpower consumption.

1.3 Classification of Clustering Algorithms

The clustering algorithms are classified in to seven categories [1]

- DS based Clustering
- Low Maintenance Clustering
- Mobility Aware Clustering
- Energy-efficient clustering
- Load-balancing clustering
- Combined-metrics-based Clustering
- Secure Clustering

DS based Clustering: The main objective of DS based Clustering is to Find a (weakly) connected dominating set to reduce the number of nodes participating in routesearch or routing table maintenance.
Low Maintenance Clustering: The main objective ofLow Maintenance Clustering to providing a cluster infrastructure for upper layer applications with minimized clustering-related maintenancecost
Mobility-aware clustering: the main objective of Mobility-aware clustering is utilizing mobile nodes' mobility behavior for Cluster construction and maintenance and assigningmobile nodes with low relative speed to the same cluster to tighten the connection in such a cluster.
Energy-efficient clustering: The main objective of Energy-efficient clustering is avoiding unnecessary energy consumption or balancing energy consumption for mobile Nodes in orderto prolong the lifetime of mobile terminals and a network.
Load-balancing clustering: The main objective of Load-balancing clustering is distributing the work load of a network more evenly into clusters by limiting the number of mobile nodes in each cluster in a defined range.
Combined-metrics-based Clustering: the main objective of Combined-metrics-based clusteringis to considering multiple metrics in cluster configuration, including node degree, mobility, battery energy,cluster size, etc., and adjusting their weighting factors for different application scenarios.

3.3.1 DS-BASED CLUSTERING

Routing based on a set of dominating nodes [1,3, 4, 5],which function as the clusterheads to relay routing informationand data packets, is a typical technique in MANETs.Such a set of nodes is called a DS. Taking a MANET as anun-weighted graph *G*, a vertex (node) subset *S* of *G* is a DS ifeach vertex in *G* either belongs to *S* or is adjacent to at leastone vertex in *S*. For example, in Fig. 2

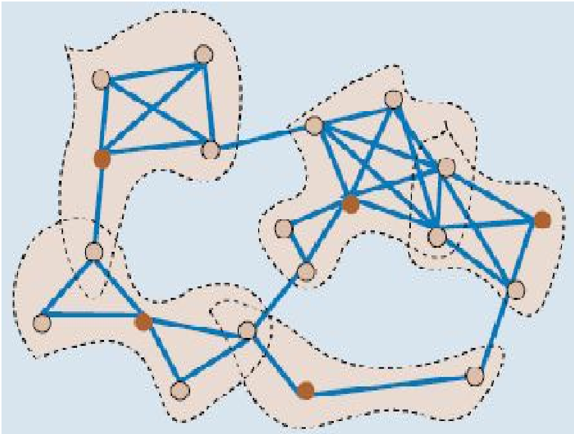

Fig.2. A Dominating Set

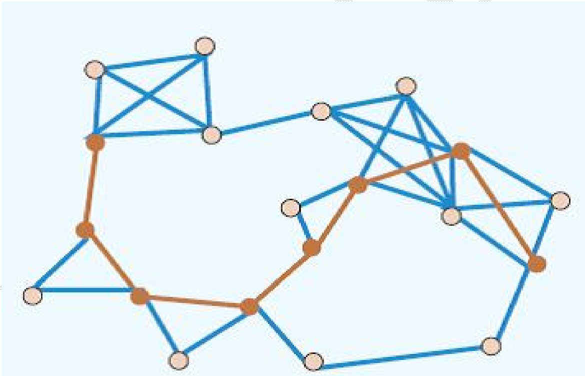

Fig.3. A Connected Dominating Set

The black vertices form a DS. Each area surrounded by the dash line is a dominatingarea of some dominating node. Then we can utilize thevertices of a DS as clusterheads and assign each vertex to acluster corresponding to a vertex that dominates it [3, 4]. ADS are called a connected DS (CDS) if all the dominatingnodes are directly connected with each other. In Fig.3 theblack vertices form a CDS and the black lines indicate thecorresponding induced subgraph of the CDS.

The idea of finding a CDS for a MANET comes from thefact that the routing process is only aggregated on mobile nodes in the DS [3]. Hence, when table-driven routing is applied, only nodes in the CDS are required to construct and maintain the routing tables. When on-demand routing i sadopted, the route search space is limited to the CDS. However, to keep a DS connected and with approximately minimumsize is not a trivial task in a dynamic environment.

The well know DS based clustering algorithms are

Wu's CDS (Connected Dominating Set) Algorithm Wu [3] proposed a distributed algorithm to find a CDS in orderto design efficient routing schemes for a MANET. Initially, every node *v* exchanges its neighbor list with all its neighbors.A mobile node sets itself as a dominating node if it has atleast two unconnected neighbors. This is called a *marking* process.Then some extension rules are implemented to reducethe size of a CDS generated from the marking process.

Chen's WCDS (Weakly Connected Dominating Set) Algorithm Chen [1] [6] pointed out that although a CDS providesexplicit information for inter-cluster routing, the number ofclusters produced by the CDS clustering is rather large andthe formed cluster structure is likely highly overlapping. Chenproposed schemes to build a weakly CDS (WCDS) by relaxingthe requirement of direct connection between neighboringdominating nodes.

3.3.2 LOW-MAINTENANCE CLUSTERING

The main criticism of a clustered network comes from theneed for extra explicit message exchange among mobile nodes for maintaining the cluster structure. When network topology changes frequently, resulting in frequent cluster topology updates the control overheads for cluster maintenance increases drastically. Thus, clustering behavior may consume a large portion of network bandwidth, drain mobile nodes' energy quickly, and override its improvement on network scalabilityand performance [1] [7]. Hence, it is important to reducethe communication overhead caused by cluster maintenance. Most low-maintenance clustering protocols aim at providing stable cluster architecture by reducing the re-affiliation rate and especially minimizing re-clustering situations.

Some of the well-known low maintenance clustering is

- ***LCC (Least Cluster Change)*****[8]**
- ***3hBAC(3-hop Between Adjacent Clusterheads*****[9]**
- ***Lin's Algorithm*** **[10]**
- ***PC (Passive Clustering*****)[11]**

3.3.3 MOBILITY-AWARE CLUSTERING

Mobility is a prominent characteristic of MANETs, and is themain factor affecting topology change and route invalidation [1] [12]. Some believe that it is important to take the mobility metric into account in cluster construction in order to form astable cluster structure and decrease itsinfluence on clustertopology. Mobility-aware clustering indicates that the clusterarchitecture is determined by the mobility behavior of mobilenodes. The idea is that by grouping mobile terminals with similarspeed into the same cluster, the intra-cluster links canbecome more tightly connected. Then the re-affiliation andre-clustering rate can be naturally decreased.

Some of well-known mobility aware clustering algorithms are as follows

- **Mobility Based Clustering (MOBIC) [12]**
- **Distributed Dynamic Clustering Algorithm [13]**

3.3.4 ENERGY-EFFICIENT CLUSTERING

Mobile nodes in a MANET normally depend on batter power supply during operation; hence the energy limitation poses a severe challenge for network performance [1, 14, 15]. A MANET should strive to reduce its energy consumption greedily in order to prolong the network lifespan. Also, a clusterhead bears extra work compared with ordinary members, and it more likely "dies" early because of excessive energyconsumption. The lack of mobile nodes due to energy depletion may cause network partition and communication interruption. Hence, it is also important to balance the energy consumption among mobile nodes to avoid node failure, especially when some mobile nodes bear special tasks or the network density is comparatively sparse. Some well-known energy efficient clustering algorithm is as follows [1]

- **ID Load Balancing Clustering (IDLBC)[17]**
- **Wu's Algorithm [18]**
- **Ryu's Algorithm [19]**

3.3.5 LOAD-BALANCING CLUSTERING

Load-balancing clustering algorithms believe that there are an optimum number of mobile nodes that a cluster can handle, especially in a clusterhead-based MANET. A too-large cluster may put too heavy of a load on the clusterheads, causing clusterheads to become the bottleneck of a MANET and reduce system throughput. A too-small cluster, however, may produce a large number of clusters and thus increase the length of hierarchical routes, resulting in longer end-to-end delay. Load-balancing clustering schemes set upper and lower limits on the number of mobile nodes that a cluster can deal with. When a cluster size exceeds its predefined limit, re-clustering procedures are invoked to adjust the number of mobile nodes in that cluster.

Some of well-known load balancing clustering algorithms are

- **Adaptive Multi-hop Clustering (AMC)[20]**
- **Degree-Load-BalancingClustering(DLBC) [21]**

3.3.6COMBINED-METRICS-BASED CLUSTERING

Combined-metrics-based clustering takes a number of metricsinto accounts for cluster configuration, including node degree, residual energy capacity, moving speed, and so on. This categoryaims at electing the most suitable clusterhead in a localarea, and does not give preference to mobile nodes with certainattributes, such as lowest ID or highest node degree. Oneadvantage of this clustering scheme is that it can flexiblyadjust the weighting factors for each metric to adjust to differentscenarios. For example, in a system where battery energyis more important, the weighting factor associated with energycapacity can be set higher [1] [22]. However, not all of theseparameters are always available and accurate, and the informationinaccuracy may affect clustering performance. Some of well-known combined-metrics based clustering algorithms are **Weighted Clustering Algorithm (WCA)** [22]

3.4.7 Secure Clustering

Algorithm is the typical clustering algorithms. Currently, most clustering algorithms assume that the network environment is reliable and has no threats. In fact, ad hoc networks are easy to be wiretapped, intruded and attacked, because of the open distributed network structure. Clusterhead and gateway are the key nodes (i.e., backbone nodes) in hierarchical ad hoc networks. If they are intruded, the network performance must decrease seriously. Therefore, we need to promote an effective detection measure to the bone cluster structure for network security, such as clustering in hierarchical ad hoc networks.Example is **A Secure Clustering Algorithm [23]**

4. Routing in Mobile MANETS

There are different criteria for designing and classifying routing protocols for wireless ad hoc networks [24]. For example, what routing information is exchanged; when and how therouting information is exchanged, when and how routes are computed and so on. We will discuss these criteria in this section.

4.1 Link state routing (LSR) vs. distance vector routing (DVR)

As with conventional wired networks, *Link state* routing (LSR) and *distance vector* routing (DVR) are two underlying mechanismsforroutinginwirelessadhocnetworks.InLSRrouting information is exchanged in the form of *link state packets* (LSP). The LSP of a node includes link information about its neighbors. Any link change will cause LSPs to be flooded into the entire network immediately. Every node can construct and maintain a global network topology from the LSPs it receives, and compute, by itself, routes to all other nodes. The problem with LSR is that excessive routing overhead may be incurred because nodes in a wireless ad hoc network move quickly and the network topology changes fast [24]

In DVR, every node maintains a distance vector which includes, but is not limited to, the triad (destination ID, next hop, (shortest) distance) for every destination.

Everynodeperiodically exchanges distance vectors with its neighbors. When a node receives distance vectors from its neighbors, it computes new routes and updates its distance vector. The complete route from a source to a destination is formed, in a distributed manner, by combining the next hop of nodes on the path from the source to the destination. The problems with DVR are slow convergence and the tendency of creating routing loops.

4.2 Precomputed routing vs. on-demand routing

Depending on when the route is computed, routing protocols can be divided into two categories: pre-computed routing and on- demand routing.Precomputed routing is also called *proactive* routing or *table- driven* routing [24]. In this method, the routes to all destinations are computed *a priori*. In order to compute routes in advance, nodes need to store the entire or partial information about link states and network topology. In order to keep the information up to date, nodes need to update their information periodically or whenever the link state or network topology changes. The ad- vantage of precomputed routing is that when a source needs to send packets to a destination, the route is already available, i.e., there is no latency. The disadvantage is that some routes may neverbeused. Another problem is that the dissemination of routing information will consume a lot of the scarce wireless network band width when the link state and network topology change fast (this is especially true in a wireless adhoc network).The conventional LSR and DVR are examples of proactive routing. We will use *precomputed* and *proactive* interchangeably in thispaper.

On-demand routing is also called *reactive* routing. In this method, the route to a destination may not exist in advance and it is computed only when the route is needed. The idea is as follows. When a source needs to send packets to a destination, it first finds a route or several routes to the destination. This process is called *route discovery*. After the route(s) are discovered, the source transmits packets along the route(s).Duringthetrans- mission of packets, the route may be broken because the node(s) on the route move away or go down. The broken route needs to be rebuilt. The process of detecting route breakage and rebuilding the route is called *route maintenance*. The major advantage of on-demand routing is that the precious bandwidth of wireless ad hoc networks is greatly saved [15] because it limits the amount of bandwidth consumed in the exchange of routing information by maintaining routes to only those destinations to which the routers need to forward data traffic.

On-demand routing also obviates the need for disseminating routing information periodically, or flooding such information whenever a link state changes. The primary problem withon-demand routing is the large latency at the beginning of the transmission caused by *route discovery*. We will use *on-demand* and *reactive* interchangeably in thispaper.Apart from proactive route computation and reactive route discovery, there is another routing mechanism, called flooding [24]. In flooding, no route will be computed or discovered. A packet is broadcast to all nodes in a network with the expectation that at least one copy of the packet will reach the destination. Scoping may be used to limit the overhead of flooding. Flooding is the easiest routing method because it requires noknowledgeofthenetworktopology. Underlighttrafficconditions flooding can be reasonably robust. However, it generates an excessive amount of traffic in heavy traffic or in a large network, and it is difficult to achieve flooding reliably when the to pology is highly dynamic. Flooding is generally used to transmit control packets (e.g., routing information), not data packets.

4.3 Periodical update vs. event-driven up- date

Routing information needs to be disseminated to network nodes in order to ensure that the knowledge of link state and network topology remains up-to-date. Based on when the routing information will bedisseminated, we can classify routing protocols as periodical update and event-driven update protocols [24].

Periodical update protocols disseminate routing information periodically. Periodical updates will simplify protocols and maintain network stability, and most importantly, enable (new) nodes to learn about the topology and the state of the network. However if the period between updates is large, the protocol may not keep the information up-to-date. On the other hand, if the period is small, too many routing packets will be disseminated which consumes the precious bandwidth of a wirelessnetwork.

In an event-driven update protocol, when events occur, (such as when a link fails or a new link appears), an update packet will be broadcast and the up-to-date status can be disseminated over the network soon. The problem might be that if the topology of networks changes rapidly, a lot of update packets will be generated and disseminated over the network which will use a lot of precious bandwidth, and furthermore, may cause too much fluctuation of routes. One solution is to use some threshold Periodical update and event-driven update mechanisms can be used together, forming what is called a hybrid update mechanism. For example, in DSDV, a node broadcast s its distance-vector periodically. Moreover, whenever a node finds that a link is broken, it distributes a messageimmediately.

4.4 Flat structure vs. hierarchical structure

In a flat structure, all nodes in a network are at the same level and have the same routing functionality. Flat routing is simple and efficient for small networks. The problem is that when a network becomes large, the volume of routing information will be large and it will take a long time for routing information to arrive at remote nodes. For large networks, hierarchical (cluster-based) routing may be used to solve the above problems[24].In hierarchical routing the nodes in the network are dynamically organized into partitions called clusters, then the clusters are aggregated again into larger partitions called super-clusters and so on. Organizing a network into clusters help maintain a relatively stable network topology. The high dynamics of membership and network topology is limited within clusters. Only stable and high level information such as the cluster level or the super-cluster level will be propagated across a long distance, thus the control traffic (or routing overhead) may be largely reduced. Within acluster, the nodes may have complete topology information about its cluster and proactive routing may be used. If thedestination is in a different cluster from the source, inter-cluster routing must be used. Inter-cluster routing is generally reactive, or a combination of proactive and reactive routing .Similar to cellular structure in cellular systems, a hierarchical cluster is readily deployable to achieve some kind of resource reuse such as frequency reuse and code reuse and interference can be reducedwhenusingdifferentspreadingcodesacrossclusters.

4.5 Centralized computation vs. distributed computation

Based on how (or where) a route is computed, there are two categories of routing protocols: decentralized computation and distributed computation.In a decentralized computation-based protocol, every node inthe network maintains global and complete information about the network topology such that the node can compute the route to a destination itself when desired. The route computation in LSR is a typical example of decentralizedcomputation [24].

In a distributed computation-based protocol, every node in the network only maintains partial and local information about the network topology. When a route needs to be computed, many nodes collaborate to compute the route. The route computation In DVR and the route discovery in on-demand routing belong to this category.

4.6 Source routing vs. hop-by-hop routing

Some routing protocols place the entire route (i.e., nodes in the route) in the headers of data packets so that the intermediate nodes only forward these packets according to the route in the header. Such a routing is called "source routing". Source routing has the advantage that intermediate nodes do not need to maintain up-to-date routing information in order to route the packets they forward, since the packets themselves already contain all the routing decisions. This fact, when coupled with on-demand route computation, eliminates the need for the periodic route advertisement and neighbor detection packets required in other kinds of protocols [24]. The biggest problem with source routing is that when the network is large and the route is long, placing the en- tire route in the header of every packet will waste a lot of scarce bandwidth.

In hop-by-hop routing, the route to a destination is distributed in the "next hop" of the nodes along the route. When a node receives a packet to a destination, it forwards the packet to the next hop corresponding to the destination. The problems are that all nodes need to maintain routing

4.6 Single path vs. multiple paths

Some routing protocols will find a single route from a source to a destination, which results in simple protocol and saves storage. Other routing protocols will find multiple routes which have the advantages of easy recovery from a route failure and being more reliable and robust. Moreover, the source can select the best one among multiple availableroutes.

5. MULTIPATH ROUTING

The most of existing routing protocols are single path routing protocols. They find single route and utilize it for data transmission from source to destination [25]. Due to dynamic topology, poor and variable wireless links, dynamic characteristics of radio channel, node failure, the currentlyusing route becomes invalid. Due to this the overhead for finding new route from source to destination may be high and extra delay for new route discovery may be introduced and data transmission becomes late [3]. To overcome this drawback by using multipath routing, it is latest trend in the MANET; it finds multiple paths from any source to destination in a single route discovery.

Due to the introduction of multipath routing, the time for searching the route will be reduced drastically and also it helps to reduce the latency for searching the other route at the situation of path failure. In MANETs, multipath routing is considered as trusted approach for ad hoc networking. Due the mobile nature or weak signal strength , the node failure occurs frequently in the MANETs. At the condition of route failure, the multipath routing serves as the best approach for finding the alternate path. The applications of multipath routing are given below [25].

- Reliability
- Fault tolerance
- Balancing Of Load
- Bandwidth aggregation
- Reduced delay
- Energy consumption
- Reduction of routing overhead
- Provide the Quality of Service(QoS)
- Improve network security and secure communication

There are two types of multipath, Node-disjoint multipath and Link-disjoint multipath. The node-disjoint multipath does not have any nodes in common, except for the source and the destination. Whereas, link-disjoint multipath does not have any common links, but may have common nodes. In the recent years, many researchers made the contribution to address the multipath routing. The several multipath on-demand routing protocols were proposed. Some well-known standard Multipath path routing Protocols are

- Ad hoc On-demand Distance Vector Multipath Routing (AODVM)
- Ad hoc On-demand Multipath Distance Vector (AOMDV)
- Split Multipath Routing (SMR)
- Multipath Source Routing (MSR)

The comparison of above on- demand Multipath Routing Protocol is shown in table1

	AODVM	AOMDV	SMR	MSR
Loop-Free paths	No	No	No	No
Node Disjoint	Yes	Yes	No	Yes
Link-Disjoint	No	Yes	Yes	No
Routing Overhead control	No	No	No	No
Complete Routes Known at source	No	No	Yes	Yes
Multipath used Simultaneously	Yes	Yes	Yes	Yes
TTL limitation	Yes	Yes	Yes	Yes
QOS Support	No	No	No	No
Multicast Support	No	No	No	No
Power / Energy Management	No	No	No	No
Security Support	No	No	NO	No

6. CONCLUSIONS

The Mobile Ad hoc Networks are essentially suitable when infrastructure is not present or difficult or costly to setup or when network setup is to be done quickly within a short period, they are very attractive for tactical communication in the military and rescue missions. The clustering is an important research area in mobile ad hoc networks because it improves the performance of flexibility and scalability when network size is huge with high mobility. Ad hoc routing faces many unique problems not present in wired networks. Particularly in MANETs where routes become obsolete frequently because of mobility and poor wireless link quality. The Multipath routing addresses these problems by providing more than one route to a destination node. Multipath routing appears to be a promising technique for ad hoc routing protocols; the multiple paths can be useful in improving the effective bandwidth of communication, responding to congestion and heavy traffic, increasing delivery reliability and security. The traffic can be distributed among multiple routes to enhance transmission reliability, provide load balancing, and secure data transmission and energy optimization. Hence in these paper surveys the different clustering algorisms different routing protocols and multipath routing protocols. The combination of cluster based multipath routing is a most efficient technique in MANETs.

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